

# **Report for 2001NH541B: Developing Phosphorus Management Guidelines for Agriculture in the Connecticut River Watershed**

- Articles in Refereed Scientific Journals:
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Report Follows:

## **Project Title: Developing Phosphorus Management Guidelines for Agriculture in the Connecticut River Watershed**

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### Problem and Research Objectives

A summary of soil test phosphorus levels in New Hampshire soil samples submitted to the UNH Analytical Services Lab during the past 3 years indicates that greater than 70% of soils from participating growers are in the high or greater range (greater than 50 mg P kg<sup>-1</sup>, Mehlich III extraction) (Buob, unpublished data). It appears that P in New Hampshire's agricultural soils could pose a greater risk to the environment than originally thought. Furthermore, it is important that high P soils be identified, as there should be little or no yield response (increase) to added P in these agricultural soils. There is currently a need to determine at what level of soil test P, and on which soil types, the risk of nonpoint source pollution from P in runoff, erosion, and leaching is greatest.

Several states are adapting an assessment tool, the Phosphorus Site Index, for determination of P contamination risks from agriculture. This approach considers environmental features controlling the fate of phosphorus at any location: site characteristics and transport factors such as soil texture, erosion, runoff potential and proximity to water bodies; chemical features such as the form of phosphorus and its association with soil components, and release of P into solution; and site management factors such as fertilizer types and application rates that influence soil P content (soil test P) (Lemunyon and Gilbert, 1993; NRCS, 1994). In 2002, New Hampshire will begin determining P Site Indices for agricultural areas. As in other states, this tool will be useful for community planners, soil surveyors, cooperative extension specialists, crop consultants, and growers.

Soil test phosphorus values must be included in the New Hampshire P Site Index, and it will be necessary to determine an appropriate test for "environmentally mobile" soil phosphorus. The most appropriate approach will be convenient, cost-effective, and accurate for New Hampshire soils. New Hampshire agricultural soils are dominantly Entisols, Inceptisols, and Spodosols. Spodosols can have relatively high P sorption capacities due to relatively high iron and aluminum sesquioxide contents (Simard et al., 1994). Due to the influence of soil pedologic characteristics on the relationship between soil test P and P sorption characteristics (Beauchemin and Simard, 1999), and the variety of soil test approaches proposed for use in environmental assessments of P in soils, this study was undertaken to determine the most appropriate soil test approach for P Site Indices in New Hampshire.

The objectives of this study were to:

- 1) Chemically and physically characterize representative agricultural soils from the Connecticut River Watershed (CRW) in New Hampshire to allow comparison of soil

types within the state and New England, and estimate the behavior of P in untested soils with known characteristics.

- 2) Determine the relationships between soil test methods used in New Hampshire and Vermont (Mehlich 3, and Modified Morgan), using the CRW/New Hampshire soils.
- 3) Determine the relationship between water-extractable P and soil test P for the CRW/NH soils. This relationship will provide information to help predict sites that may be “susceptible” to phosphorus due to a high or very high levels of P in the soil test results.
- 4) Produce P sorption and desorption curves for a subset of the soils. The curves (i.e., the equations describing them) will be used to help group soil types based on their native abilities to hold or release phosphorus.

## Methodology

### *Soil Collection*

Soils were chosen to represent both agriculturally productive soils in the Connecticut River Watershed and the broad diversity of soils farmed in the state of New Hampshire. Once identified, soil samples were collected by horizon (A, B, and C horizons) with the assistance of a state NRCS soil scientist (Joe Homer), to confirm that the field sites were mapped correctly and that the soil series being collected were within the soil series description criteria. Although horizons were collected to a depth of 20 in (50 cm) the data described will be that of the A horizons. The depth of the A horizons ranged from 5 in (13 cm) to 12 in (30.5 cm) and the crop was either corn or hay. Each horizon was described and recorded in the field as it was collected. Approximately 1 gallon of soil from each horizon was collected. Soils were then air dried and sieved (2 mm) prior to chemical characterization.

### *Soil Characterization*

Characterization data included textural analysis, organic matter content, deionized water pH, SMP buffer pH, Modified Morgan (MM) Al, Fe and P, and Mehlich III (M3) Al, Fe, and P. The MM and  $\text{CaCl}_2$  pH determinations for the soils used in this study were provided by Drs. W. E. Jokela and F. Magdoff at the University of Vermont. The MM results were generated at the University of Vermont (UVM) Soils Laboratory with UVM standard methods of analysis. The textural analysis was performed using the hydrometer method (Bouyoucus, 1962). Organic matter content was determined using loss on ignition (LOI) at 360 degrees C, which is the standard method used by the UNH Analytical Services Lab. Deionized water pH and SMP buffer pH were determined using standard methods (Sims and Eckert, 1995) with a water to soil ratio of 1:1 (v:v). M3 analyses were also performed using standard methods (Sims, 1995) and samples were analyzed using a Vista AX/CCD Simultaneous ICP-AES (Varian).

### *Dilute Salt-Extractable Phosphorus*

Water extractable (0.01 M CaCl<sub>2</sub>) P was determined with the procedure described by Self-Davis et al. (2000). After one hour on a reciprocating shaker, samples were centrifuged for 10 min at 4000 rpm and filtered through a Whatman No. 42 filter paper. Samples were then analyzed by ICP-AES for total dissolved P.

### *Sorption Isotherm Determination*

Sorption isotherms were obtained using the method developed by Graetz and Nair (2000). A substitution of 0.01 M KCl was made for the 0.01 M CaCl<sub>2</sub> background electrolyte to avoid precipitation of Ca in the neutral soils. From these data, Langmuir and Freundlich constants were determined, and sorption maxima (Langmuir b values) were calculated. Phosphorus sorption indexes (PSI) were also determined, using the method described by Sims (2000). All samples were shaken for the appropriate time and then filtered using 0.45µm syringe filters. All samples were then analyzed using ICP-AES.

### Principal Findings and Significance

Soil characteristics are given in Table 1 for the A horizons of soils collected for this study.

### *Soil Test Method Comparison and Phosphorus Saturation Indices*

The relationship between Mehlich III extractions and Modified Morgan extractions was determined by comparing phosphorus saturation index values, with both methods. Phosphorus saturation indices were calculated with extractable phosphorus, iron, and aluminum obtained with M3 and MM extractions, as  $P_{\text{extr}}/(Al + Fe)_{\text{extr}}$  (mmol kg<sup>-1</sup> for P, Fe, and Al). In general, the relationship between M3 and MM saturation indices was not linear (regression information:  $M3\ P = 0.06 \cdot \ln(MM\ P) + 0.24$ ,  $r^2 = 0.91$ ). The overall relationship reflects the positive relationship between M3 and MM extractable P, best described as a non-linear relationship (regression information:  $M3\ P = 4.31 \cdot \ln(MM\ P) + 11.8$ ,  $r^2 = 0.74$ ), and that of M3 and MM extractable (Al + Fe), a weak linear relationship (regression information:  $M3\ (Al + Fe) = 6.75 \cdot (MM\ (Al + Fe)) + 42.2$ ,  $r^2 = 0.42$ ). The latter relationship is influenced by a poor relationship between M3 and MM extractable iron (linear  $r^2 = 0.004$ ). Mehlich III extraction was initially designed to extract metals, and has been adopted for nutrient extraction as well. The weak relationships between M3 and MM extractable metals suggests that either the M3 extraction (utilizing EDTA and fluoride) accesses metals and possibly P in primary and phyllosilicate minerals, as well as those in sesquioxides and metal phosphates. Alternatively, the MM extraction may not efficiently extract sesquioxide metals or metal phosphates. Extractable (Al + Fe) increased in the order Entisols < Inceptisols < Spodosols for both extractions (Table 2).

### *Water-Extractable Metals*

Mehlich III P saturation index appears to be useful for predicting water/calcium chloride-extractable P. The water/calcium chloride-extractable P and the M3 P saturation index are closely related (linear  $r^2 = 0.90$  with Pittstown and Dartmouth-1 excluded). Slightly stronger is the relationship between M3 P and water/calcium chloride-extractable P (linear  $r^2 = 0.92$  with Pittstown and Dartmouth-1 excluded). MM extraction provides slightly lower  $r^2$  values in some cases (Table 3). The M3-extractable P concentration of the New Hampshire agricultural soils was found to be lower than (ranging from 72 to 582 mg kg<sup>-1</sup>) that of the Vermont soils (ranging from 500 to 1600 mg kg<sup>-1</sup>) described by Magdoff et al. (1999).

The Pittstown series soils and samples from a clay-rich profile of the Dartmouth series (Dartmouth-1), were outliers on regression curves and were therefore excluded from the regressions. Both soils are Aquic Dystrichrepts (Homer, 1999; Aquic Dystrichrepts by Soil Taxonomy, 1999), and both have high pHs relative to other soils (pH > 7). The clay-rich Dartmouth samples were relatively high in extractable P compared to other soils. The Pittstown soils were relatively low in extractable Al, while relatively high in extractable Fe compared to other samples.

Soils were grouped by soil order to compare means and standard deviations of water/calcium chloride-extractable P, M3 P saturation values, and MM P saturation values. As expected, the largest standard deviations were observed for Entisols, for all three of the parameters with one exception (Table 4). Spodosols had the lowest concentrations and standard deviations for all three parameters.

### *Sorption Isotherms*

Batch phosphorus sorption isotherms were generated by treating soils with 0 to 12 mg L<sup>-1</sup> P in the form of phosphate. The sorption isotherms represent phosphate-P sorption by the soil, rather than total P sorption. The isotherm data were fitted with the Langmuir model by plotting  $C^*$  versus  $(C^*/(x/m)^*)$ , where  $C^*$  is the equilibrium concentration of P in the treated soil solution minus the equilibrium concentration of P in the “blank” solution (mmol P L<sup>-1</sup>), and  $(x/m)^*$  is the concentration of added P sorbed by the soil (mmol P kg<sup>-1</sup> soil). Freundlich isotherms were generated by plotting  $\log_{10} C^*$  versus  $\log_{10} (x/m)^*$ . Sorption isotherms for most soils fit the Freundlich model slightly better than they fit the Langmuir model (Table 5). Spodosols had the highest Langmuir b (sorption maxima) of the three soil orders, while Entisols had the lowest. Spodosols also had the highest Freundlich  $K_f$ , and the lowest Freundlich linearity (1/n). Entisols had the lowest Freundlich  $K_f$  and highest linearity. Inceptisols were intermediate with respect to sorption parameters. Langmuir sorption maxima values were linearly related to Freundlich  $K_f$  values ( $r^2 = 0.94$ ). Sorption analyses did not include Colton, Adams, and Fryeburg samples as these samples were not available when sorption experiments were performed.

Performing sorption experiments on soils is time consuming, and not likely to be a time and cost-effective approach for determining environmentally-mobile P for most laboratories. For this reason, phosphorus sorption indices (PSI) were determined by the method of Sims (2000). PSI is calculated as the mass of P sorbed ( $\text{mg kg}^{-1}$ ) divided by the  $\log_{10}$  of the mass of P sorbed. Strong linear relationships were observed for the New Hampshire soils when PSI was compared with Langmuir sorption maxima (b) values ( $r^2 = 0.96$ ) and Freundlich  $K_f$  values ( $r^2 = 0.95$ ). A strong relationship between sorption maxima and PSI was also observed by Simard et al. (1994) for Quebec soils. Because there is a close relationship between traditional sorption parameters and PSI, it appears that it would be possible to characterize phosphate sorption for New Hampshire soils using the one-step PSI approach in lieu of determining sorption isotherms.

### *Conclusions*

A suitable approach for testing New Hampshire soils for environmentally-mobile P appears to include a combination of Mehlich III extractions for soil test P, PSI measurements to determine sorption capacities, and water/calcium chloride extractions to estimate P concentrations released to soil solutions. Rather than a single soil test P value as is typical in Phosphorus Site Indices, all three of the parameters could be considered as P quantity, P capacity, and immediate P release terms, respectively.

The Spodosols examined had both the highest sorption affinity for P, and currently the lowest extractable P (including water/calcium chloride-extractable P). If agricultural management of P does not change on these soils, assuming that the soils obtained for this study are representative of all agricultural Spodosols in New Hampshire, P associated with Spodosols may pose minimal threat to the environment. If, however, additional P is added to these soils in the future, they could pose a threat to the environment where erosion is an issue, because these soils can retain relatively high quantities of P that could be carried to surface water on soil particles. Seasonally-saturated Spodosols were not sampled in this study, and may not fit the pattern observed. Entisols and Inceptisols were variable with respect to sorption capacities and extractable P. The relatively lower sorption capacities of Entisols and Inceptisols, coupled with their higher P contents (especially for samples of the Hadley and Windsor soils) suggest that P runoff and leaching are potential considerations for these soil orders.

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Table 1. Characteristics of Ap horizons of New Hampshire soils.

Soil Series	Soil Order	pH <sup>1</sup> (CaCl <sub>2</sub> )	pH water <sup>2</sup> (UNH)	pH SMP	% Clay	% Sand	% OM
Hadley	Entisol	5.7	6.27	6.79	13	34	5.0
Quonset	Entisol	5.8	5.96	6.93	10	63	4.5
Suncook	Entisol	5.8	5.78	7.20	9	72	1.4
Sunday	Entisol	5.2	5.8	6.96	8	74	1.8
Windsor	Entisol	6.4	6.95	7.04	5	74	5.4
Agawam	Inceptisol	6.2	6.42	6.96	11	12	1.4
Bernardston	Inceptisol	5.9	6.17	6.80	10	51	9.7
Dartmouth-1	Inceptisol	7.4	7.72	7.41	23	35	9.1
Dartmouth-2	Inceptisol	5.8	6.34	6.90	11	20	3.7
Hitchcock Ap1	Inceptisol	5.3	5.43	6.58	13	33	5.5
Hitchcock Ap2	Inceptisol	6.7	5.90	6.79	13	34	4.3
Occum	Inceptisol	5.3	5.95	6.96	14	32	2.7
Ondawa	Inceptisol	5.5	6.21	6.90	7	65	3.2
Pittstown	Inceptisol	6.3	7.09	7.22	9	54	7.6
Adams	Spodosol	6.0	6.31	6.58	10	69	9.0
Colton	Spodosol	5.9	6.49	6.88	8	79	4.9
Groveton	Spodosol	6.1	6.76	6.67	10	61	6.0
Marlow	Spodosol	5.2	5.35	6.37	15	39	6.9
Monadnock	Spodosol	6.1	6.65	6.75	15	64	9.4
Tunbridge	Spodosol	4.8	5.21	5.98	12	52	10

<sup>1</sup>1:2 soil:solution, 0.01M CaCl<sub>2</sub> (UVM).

<sup>2</sup>1:1 soil:deionized water.

Table 2. Extractable P and (Al + Fe) concentrations by soil order.

Soil Order	Mean M3 P (Std. Dev.) (mmol kg <sup>-1</sup> )	Mean MM P (Std. Dev.) (mmol kg <sup>-1</sup> )	Mean M3 (Al + Fe) (Std. Dev.) (mmol kg <sup>-1</sup> )	Mean MM (Al + Fe) (Std. Dev.) (mmol kg <sup>-1</sup> )
Entisols	8.38 (8.04)	0.77 (0.74)	48 (12)	1.4 (0.9)
Inceptisols	8.72 (4.34)	0.54 (0.44)	59 (13)	1.8 (1.1)
Spodosols	4.80 (2.21)	0.24 (0.14)	67 (6)	3.0 (0.7)



Table 3. Linear regression results for water-extractable P, Modified Morgan extractable P, and P saturation indices based on Modified Morgan extractions. Pittstown and Dartmouth-1 samples were excluded from regressions.

Regression	Linear $r^2$
MM P vs MM P sat <sup>1</sup>	0.90
Water/CaCl <sub>2</sub> -extractable P vs MM P sat <sup>1</sup>	0.74
Water/CaCl <sub>2</sub> -extractable P vs MM P	0.90

<sup>1</sup>MM P sat calculated as Modified Morgan extractable P/(Al+Fe)

Table 4. Average and standard deviations of water/calcium chloride-extractable P, Mehlich III and Modified Morgan P saturation values.

Soil Order	No. Obs.	Water/CaCl <sub>2</sub> Extr-P (mmol kg <sup>-1</sup> ) Mean (Std Dev)	Mehlich III P sat. P/(Al+Fe) Mean <sup>2</sup> (Std Dev)	Modified Morgan P sat. P/(Al+Fe) Mean <sup>2</sup> (Std Dev)
Entisols	5	0.27 (0.31)	0.16 (0.14)	1.01 (1.05)
Inceptisols <sup>1</sup>	9	0.17 (0.14)	0.18 (0.10)	0.96 (1.32)
Spodosols	6	0.12 (0.08)	0.09 (0.05)	0.12 (0.09)

<sup>1</sup>Pittstown and Dartmouth-1 series soils included. Modified Morgan P saturation mean and standard deviations without Dartmouth-1 and Pittstown soils are 0.25 (0.18).

<sup>2</sup>mmol kg<sup>-1</sup> P, Al and Fe

Table 5. Langmuir and Freundlich sorption parameters by soil order.

Soil Order	Entisols	Inceptisols	Spodosols	All Soils
No. Obs.	5	9	4	18
Langmuir b				
Mean (Std Dev)	3.67 (1.77)	5.70 (1.92)	8.32 (1.14)	5.72 (2.35)
Langmuir				
Mean $r^2$	0.91	0.91	0.94	0.91
Freundlich 1/n				
Mean (Std Dev)	0.586 (0.125)	0.557 (0.070)	0.521 (0.125)	0.557 (0.096)
Freundlich K <sub>f</sub>				
Mean (Std Dev)	0.781 (0.253)	0.900 (0.293)	1.389 (0.196)	0.975 (0.341)
Freundlich				
Mean $r^2$	0.98	0.99	0.98	0.99

### Students involved

This project had funding for only student labor. One undergraduate student and an hourly graduate student were involved in textural analyses of the soils.

### Publications, Reports, and Presentations

#### Publication:

Buob, T.E. and E.A. Rochette. Status of phosphorus in soils of the Connecticut River Watershed in New Hampshire. *Submitted to Communications in Soil Science and Plant Analysis*.

#### Presentations:

Buob, T.E. NRCS State Nutrient Management Committee, Durham, NH. April 2001

Buob, T.E. American Society of Agronomy Poster Session, Charlotte, NC. Oct 2001

Buob, T.E. Merrimack County NRCS Nutrient Management Program, Concord, NH. Nov 2001

Buob, T.E. New Hampshire Nutrient Management Planning, Durham, NH Jan 2002

Buob, T.E. Sullivan/Cheshire County NRCS Nutrient Management Planning, Charlestown, NH. Feb 2002

Buob, T.E. UNH Cooperative Extension Inservice Training, Kingman Farm, Madbury, NH March 2002

Buob, T.E. UNH Cooperative Extension State Meeting, Poster Session, Concord NH. June 2002